...Big Performance, Smaller Satellites

Development of a Nitrous Oxide Monopropellant Thruster

Presenter: Stephen Mauthe

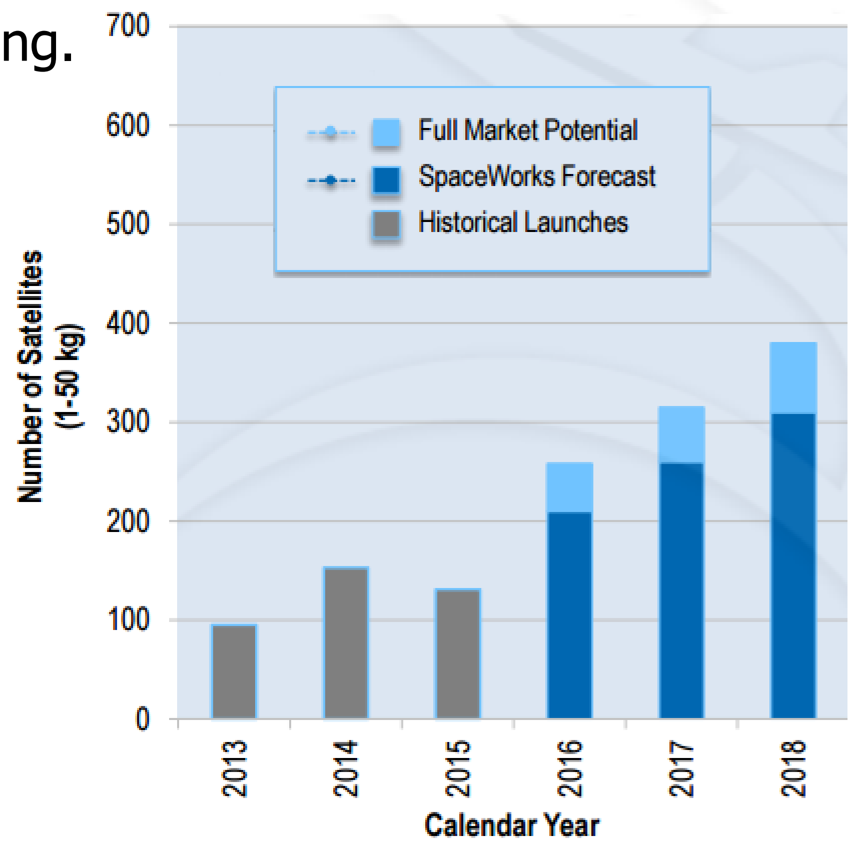
Authors: V. Tarantini, B. Risi, R. Spina, N. Orr, R. Zee

Space Flight Laboratory
Toronto, Canada

2016 CubeSat Developers' Workshop – Utah, USA

Motivation

- The use of small satellites is booming.
- Capabilities are always evolving:
  - Powerful computing
  - High performance 3-axis ADCS
  - High speed communications
  - Highly capable payloads
- Propulsion requirements
  - Orbit acquisition
  - Station-keeping
  - Formation flying
  - Collision avoidance
  - De-orbit



Background

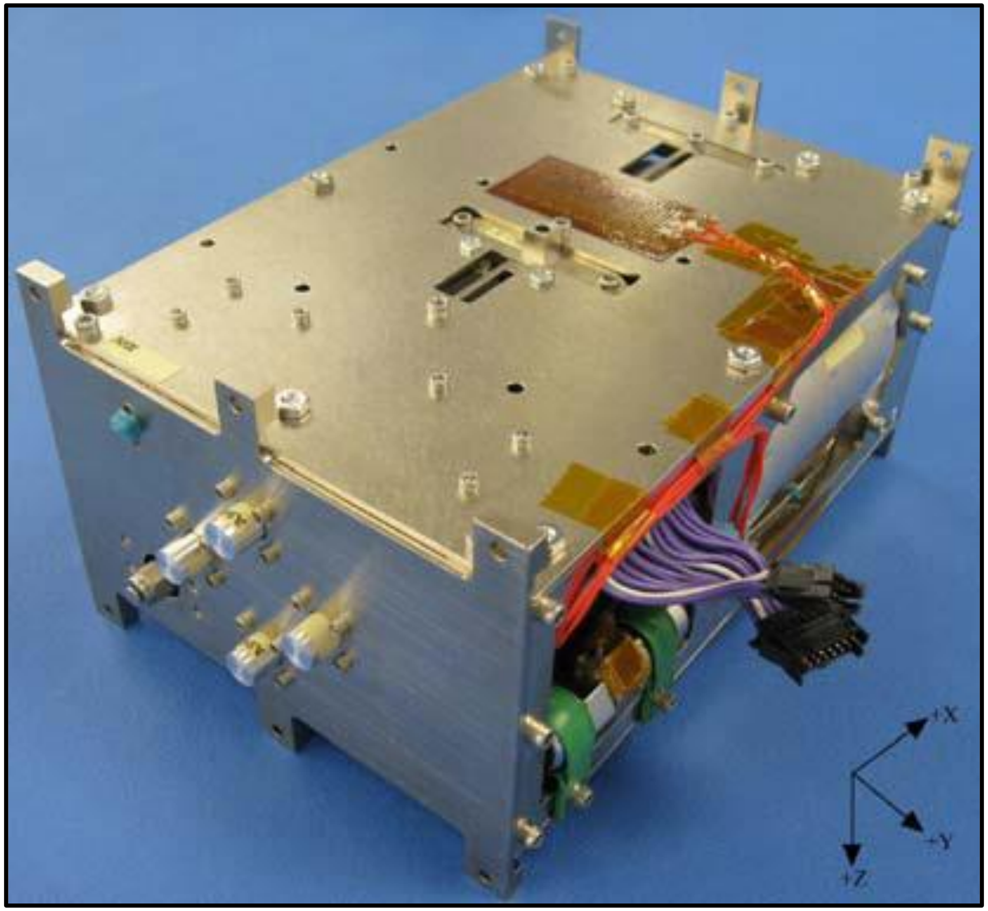
- 2008: NANOPS (the CanX-2 mission)
- 2014: CNAPS (the CanX-4&5 mission)

- SFL wins a Canadian Space Agency contract to develop next generation propulsion systems.

- Two systems chosen: CHT and monopropellant.

- The primary propulsion system requirements were:
  - 150 kg spacecraft
  - 100 m/s delta v
  - >50 mN thrust
  - <25 kg wet mass
  - Safety and ease of handing

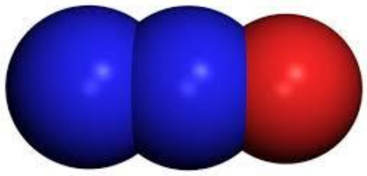
CNAPS



- Enabled the success of the CanX-4&5 Formation Flying Mission in 2014.
- SF_6-based cold gas propulsion system
- F = 12 mN to 50 mN
- I_{sp} = 45 s

Nitrous oxide (N_2O)

- Nitrous oxide is:
  - Safe to handle; i.e., it is non-toxic, non-flammable, and ~non-explosive.
  - Self-pressurizing (733 psia at 20 °C).
  - Easily obtainable.
  - A decent resistojet propellant.
  - Capable of being operated as a monopropellant.



SFL's Resistojet

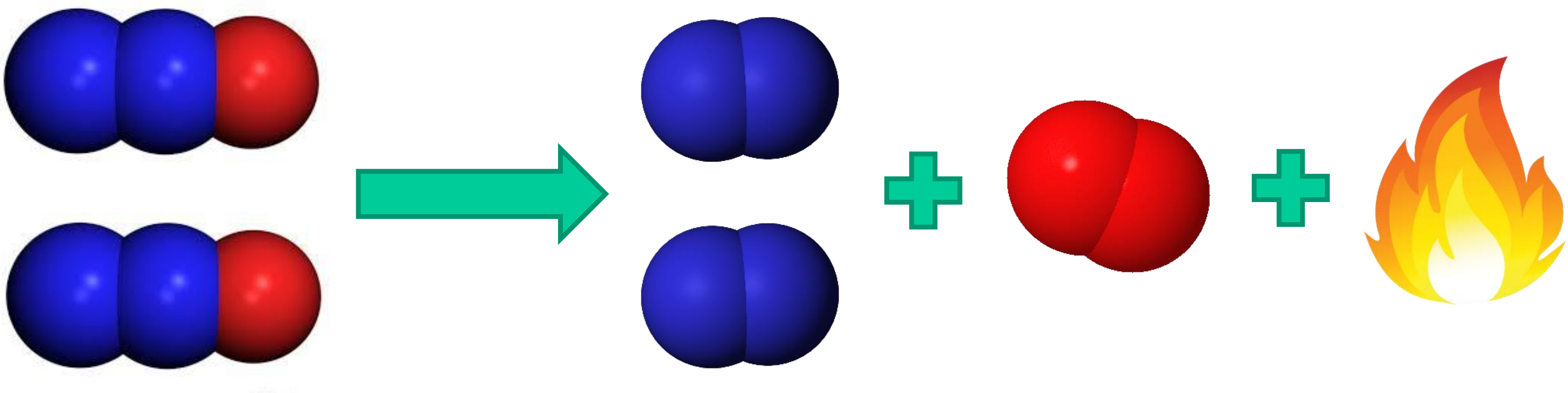
Performance with Nitrous Oxide (N_2O)

- I_{sp} = 105 s
- F = 100 mN
- P = 75 W
- m_p = 13.6 kg

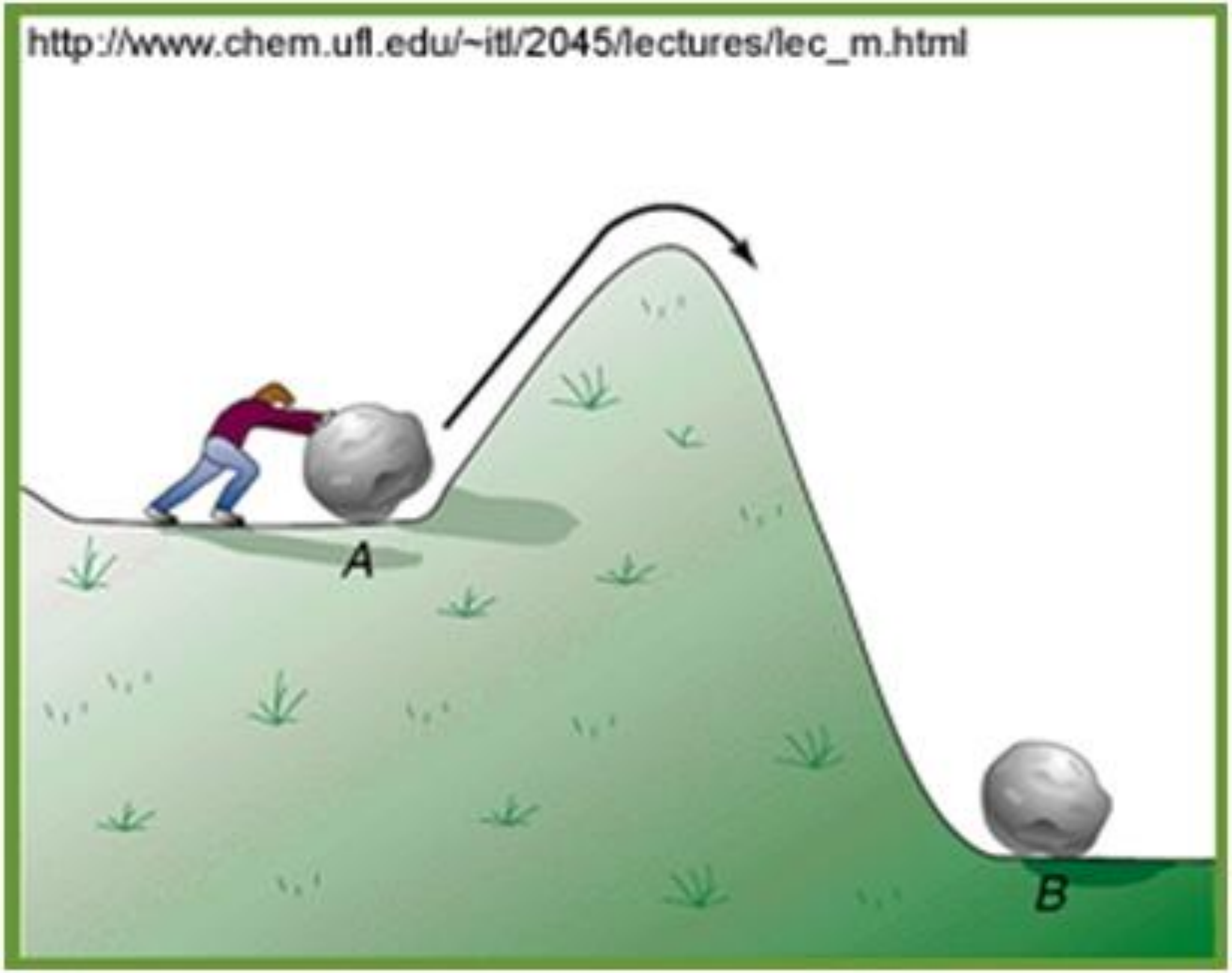
Monopropellant

- Under the right conditions nitrous oxide will exothermically decompose according to:

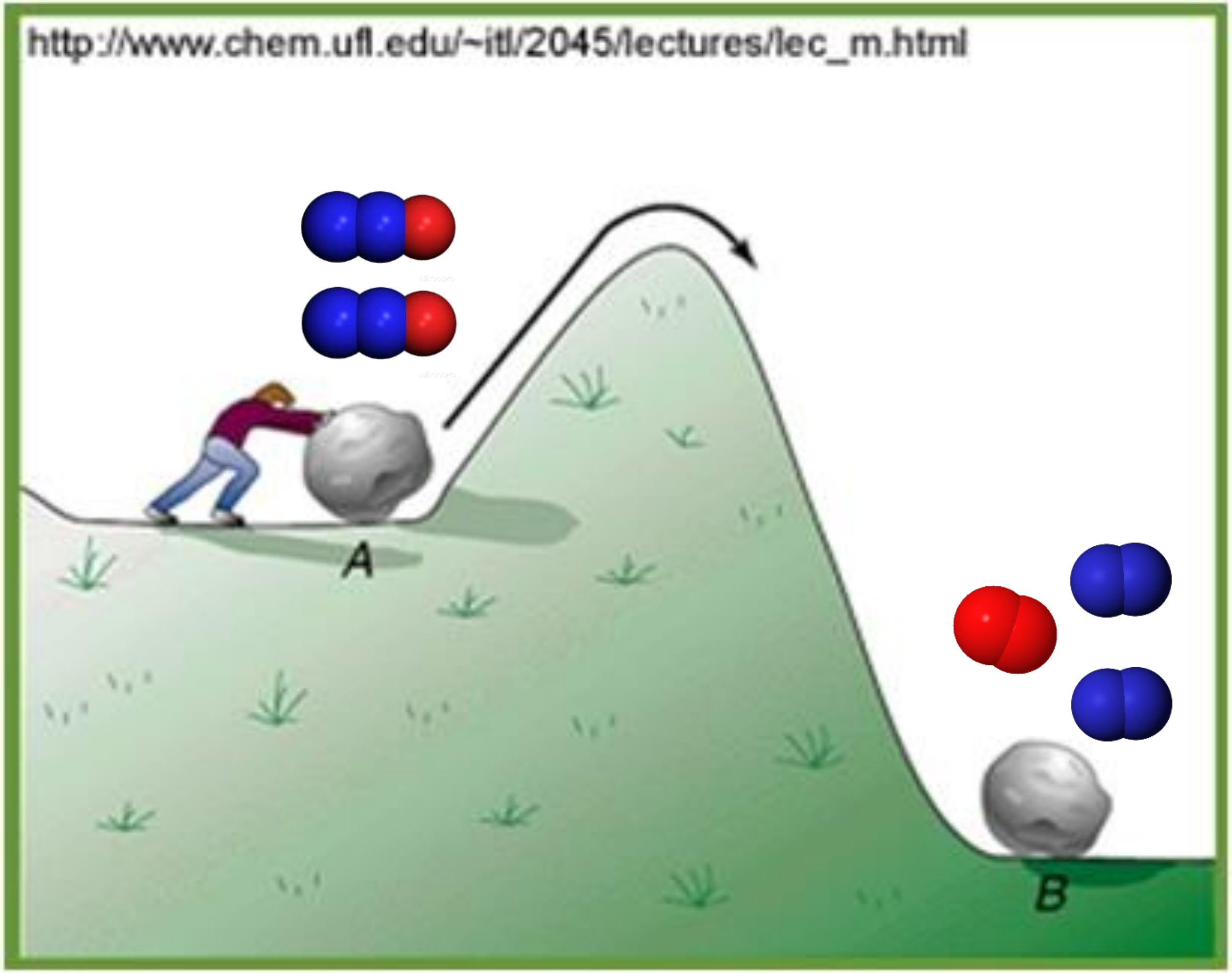
$$N_2O \rightarrow N_2 + \frac{1}{2}O_2 - 82\ \frac{\text{kJ}}{\text{mol}}$$



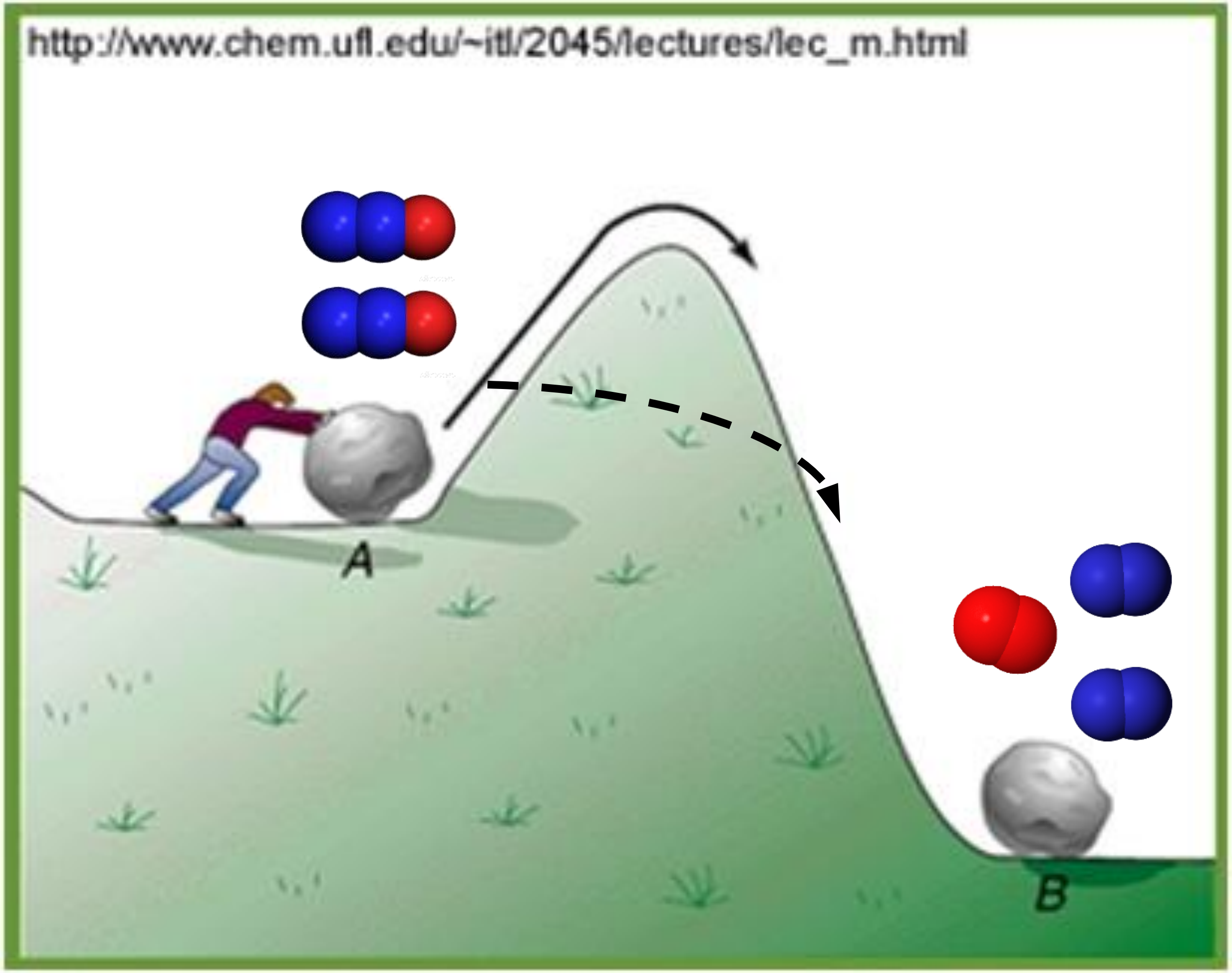
Monopropellant



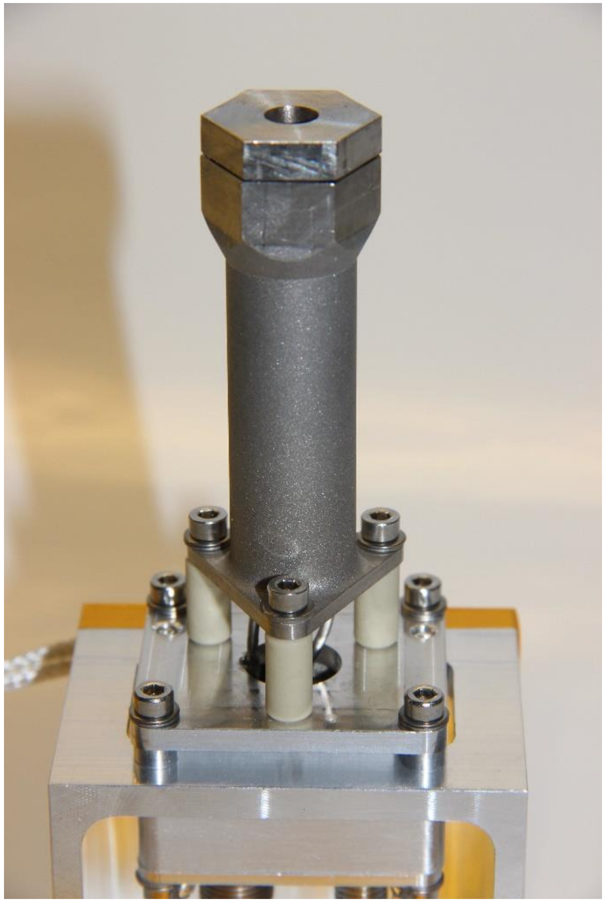
Monopropellant



Monopropellant

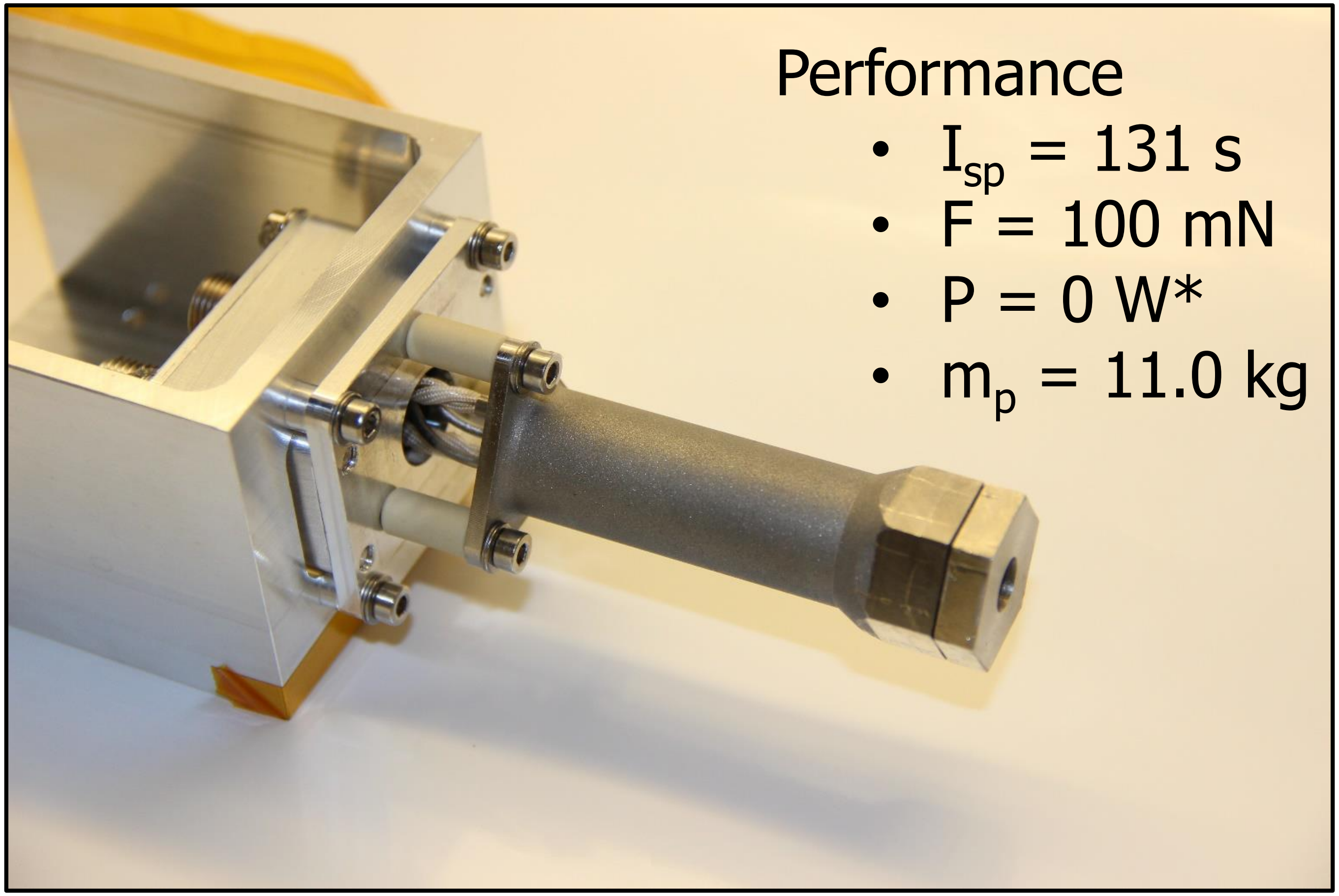


Nitro-100



Thruster performance	
Thrust [mN]	100
Specific impulse [s]	131
Mass flow rate [mg/s]	78
Chamber details	
Diameter [mm]	15.0
Max. temperature [°C]	700
Casing material	Stainless steel 316
Radiation shield material	Aluminum 6061-T6
Temperature feedback	K-type thermocouple
Catalyst pack	
Catalyst material	Rhodium metal (Rh)
Support material	γ-alumina (γ-Al_2O_3)
Heater voltage [VDC]	28
Heater power [W]	30
Pre-heat	
Pre-heat temperature [°C]	400
Pre-heat duration [minutes]	<5

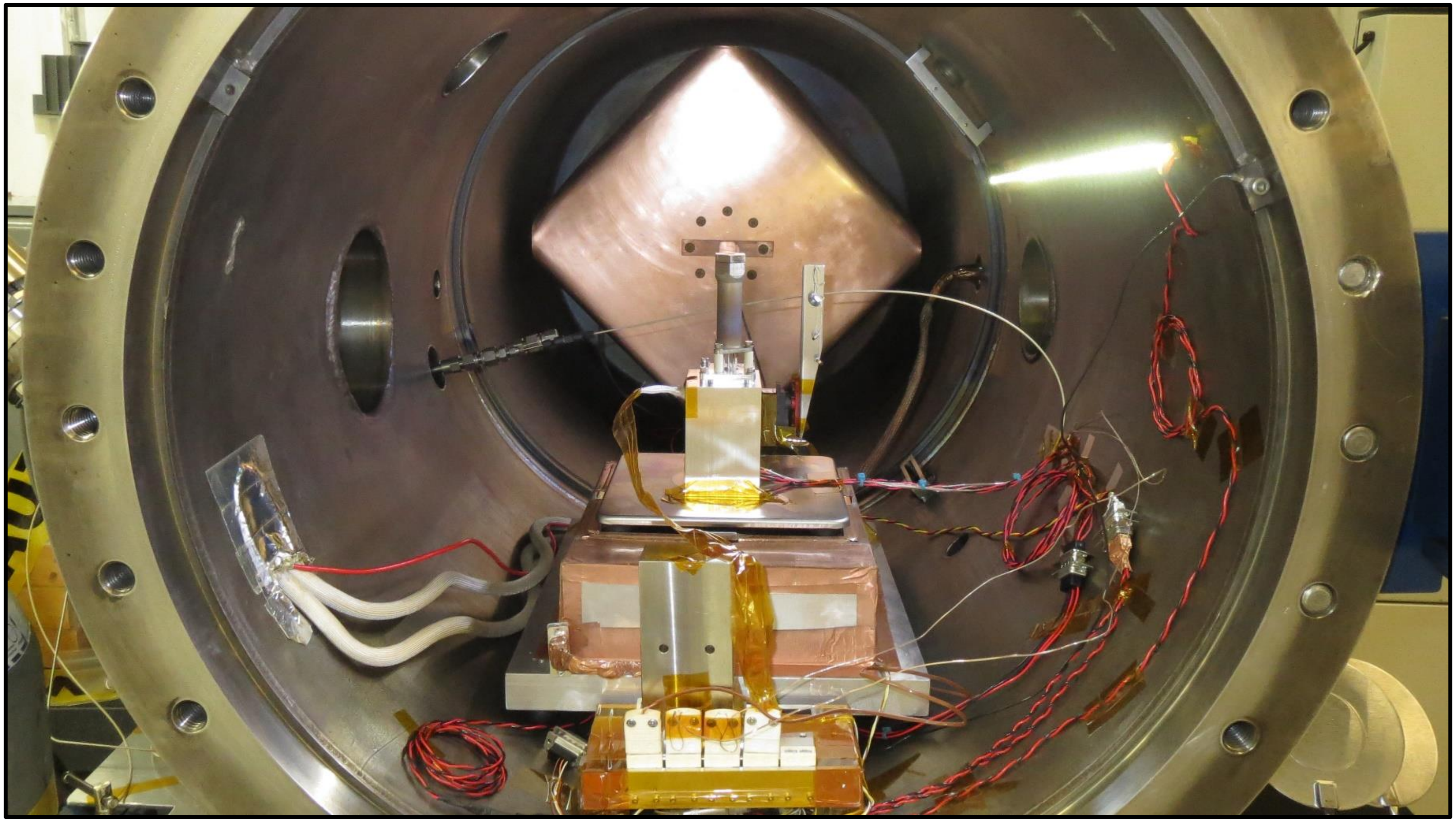
Nitro-100



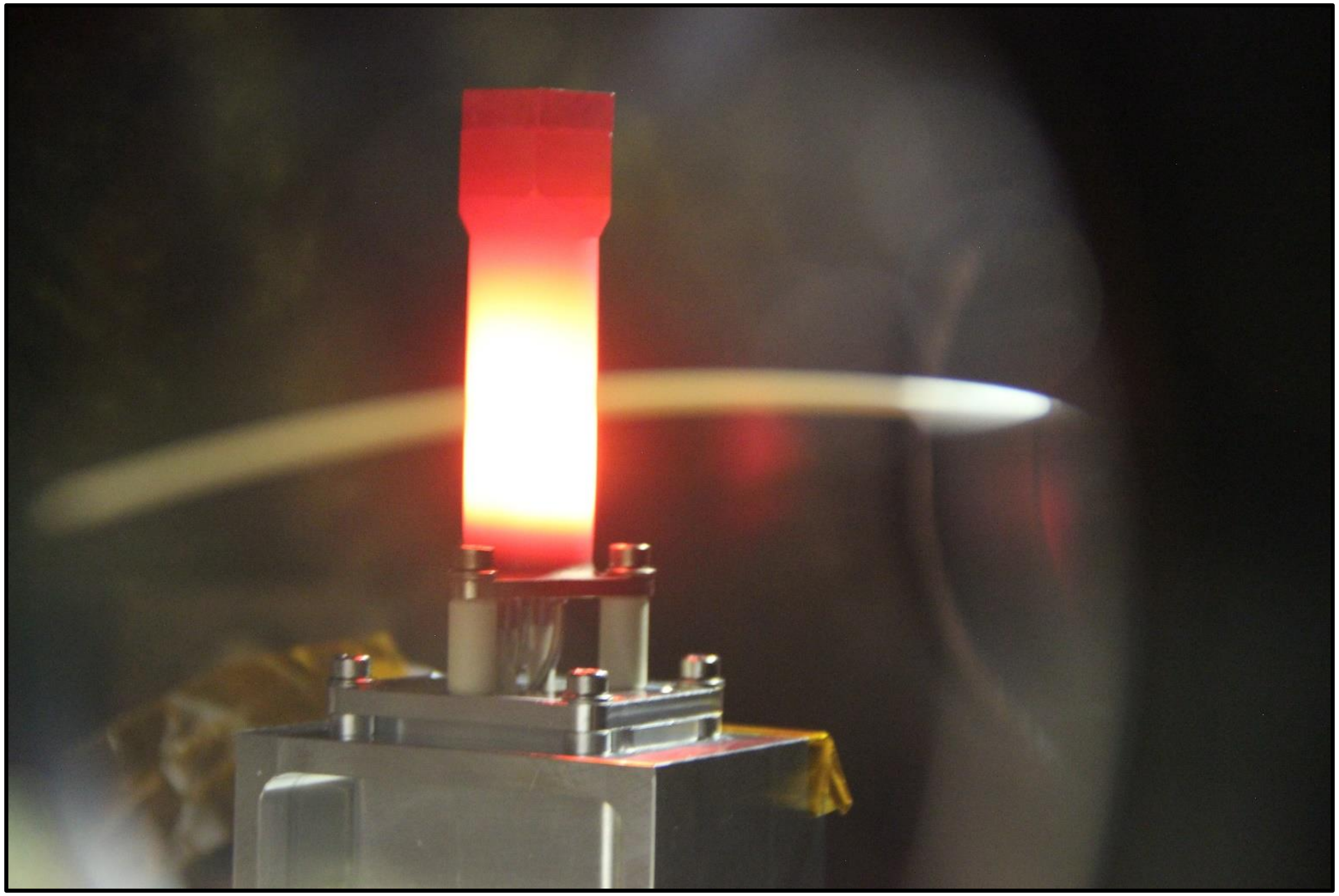
Performance

- I_{sp} = 131 s
- F = 100 mN
- P = 0 W*
- m_p = 11.0 kg

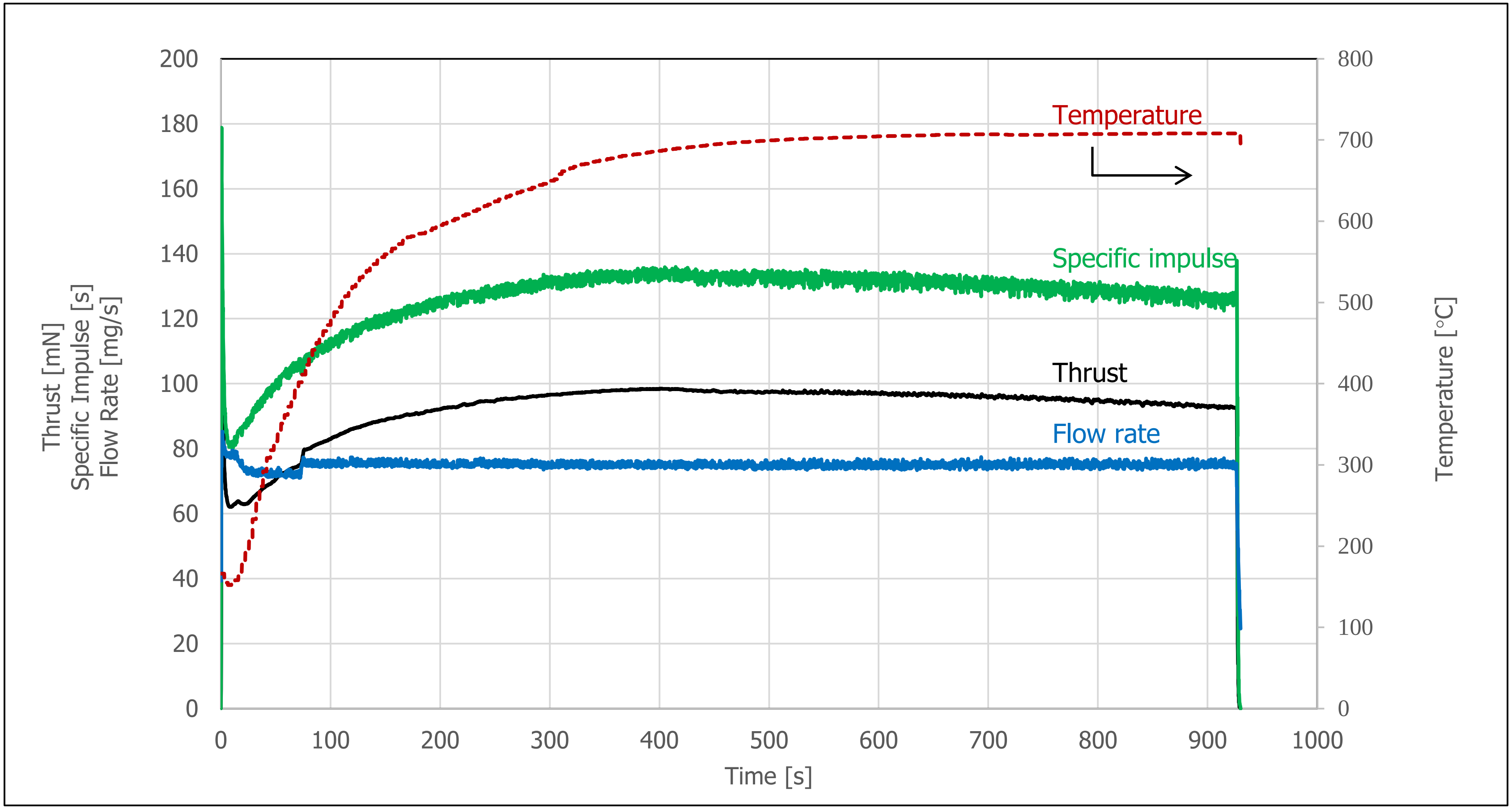
Vacuum thrust testing



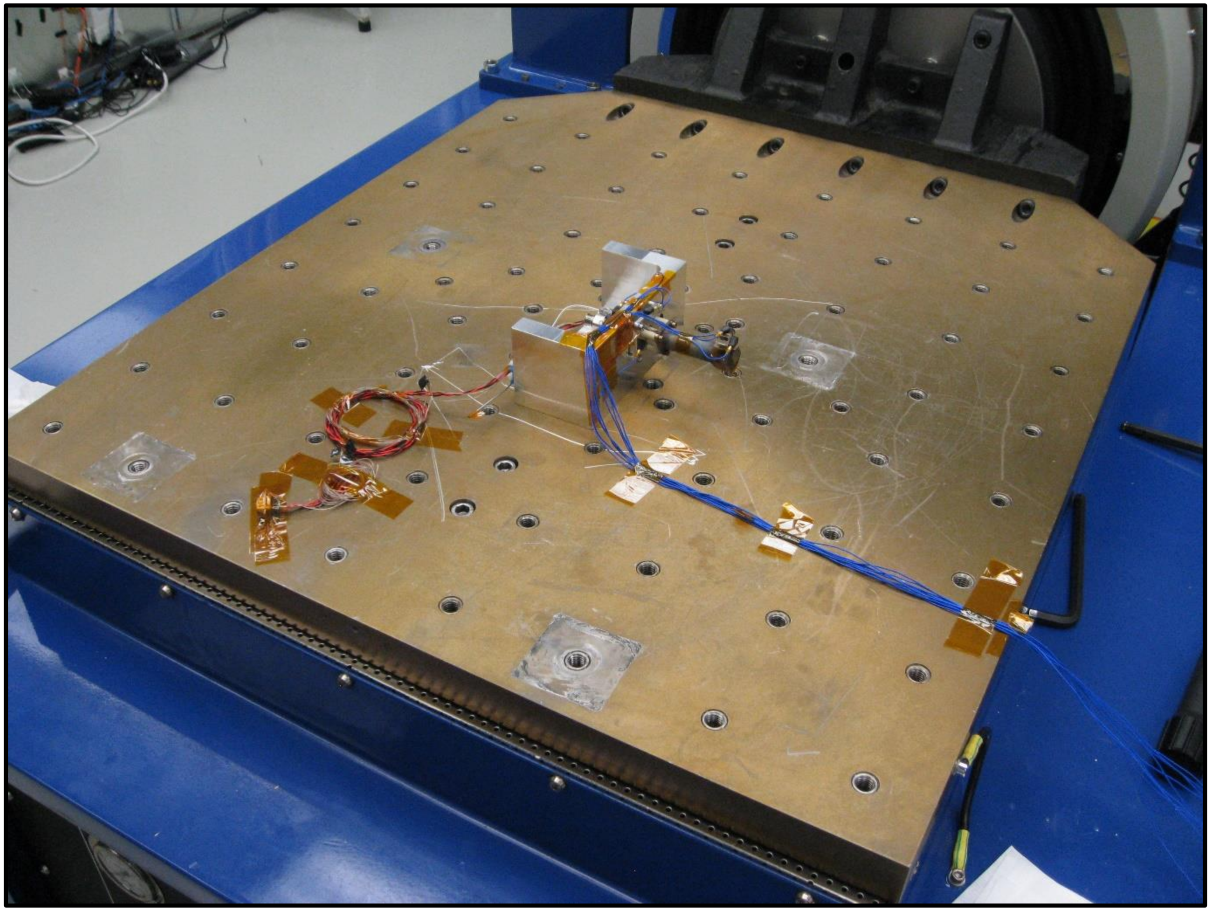
Vacuum thrust testing



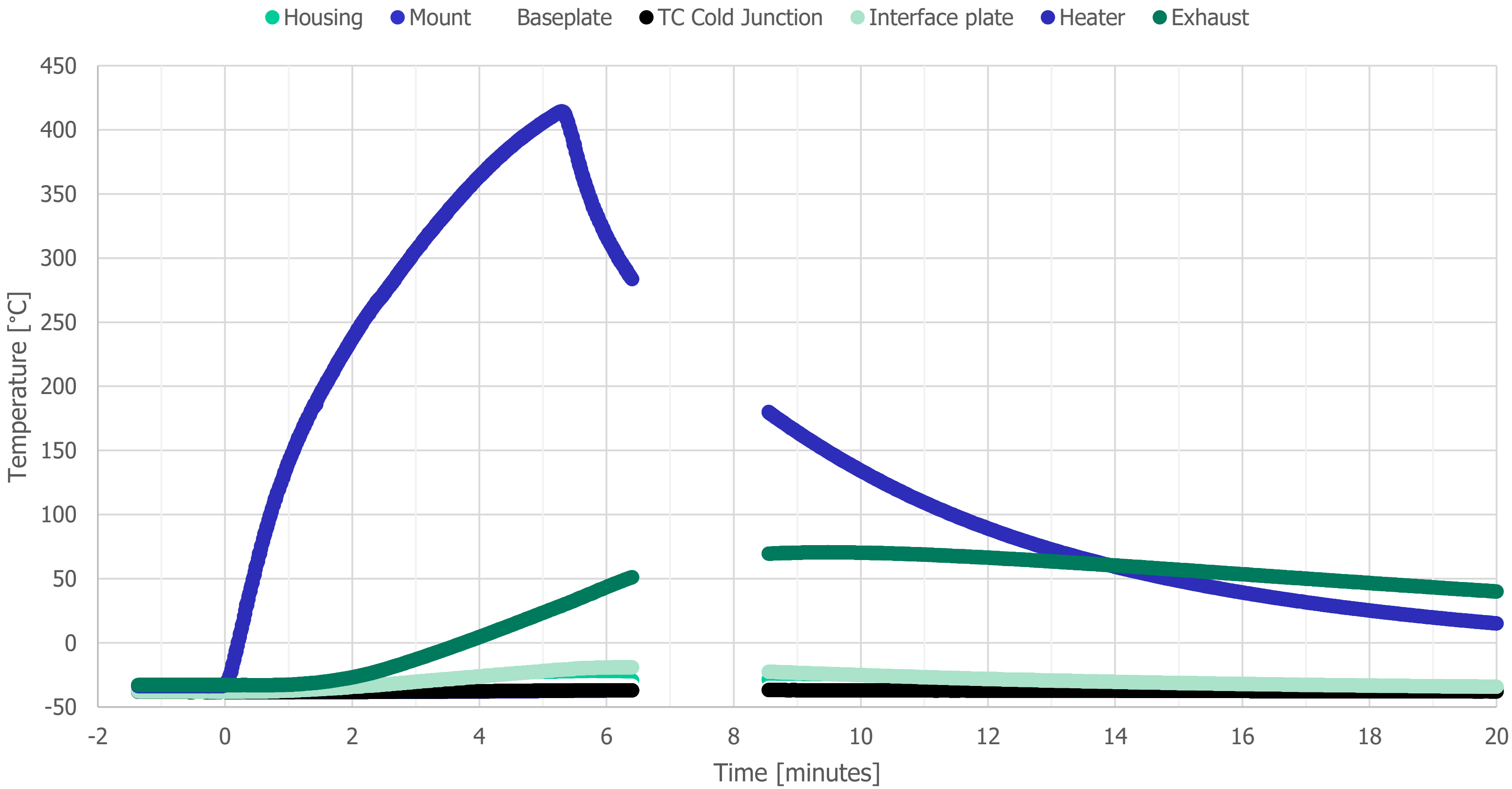
Vacuum thrust test



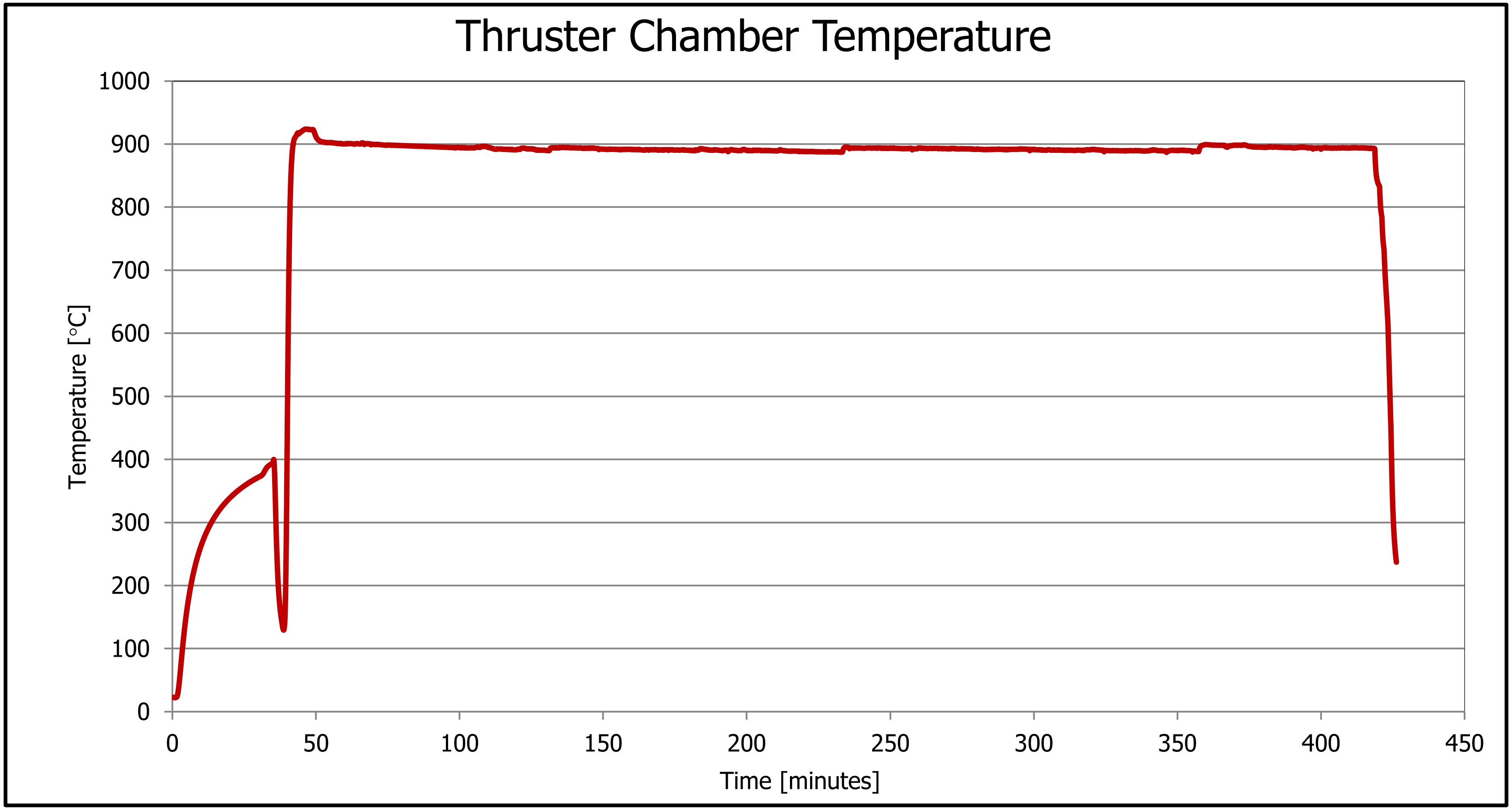
Vibration testing



Preheat from cold



Lifetime testing



Summary

- A nitrous oxide-based monopropellant thruster was developed and qualified.
- The thruster provides 100 mN at 131 s while requiring no power following pre-heat.
- The propellant to provide 100 m/s to a 150 kg spacecraft is 11 kg.

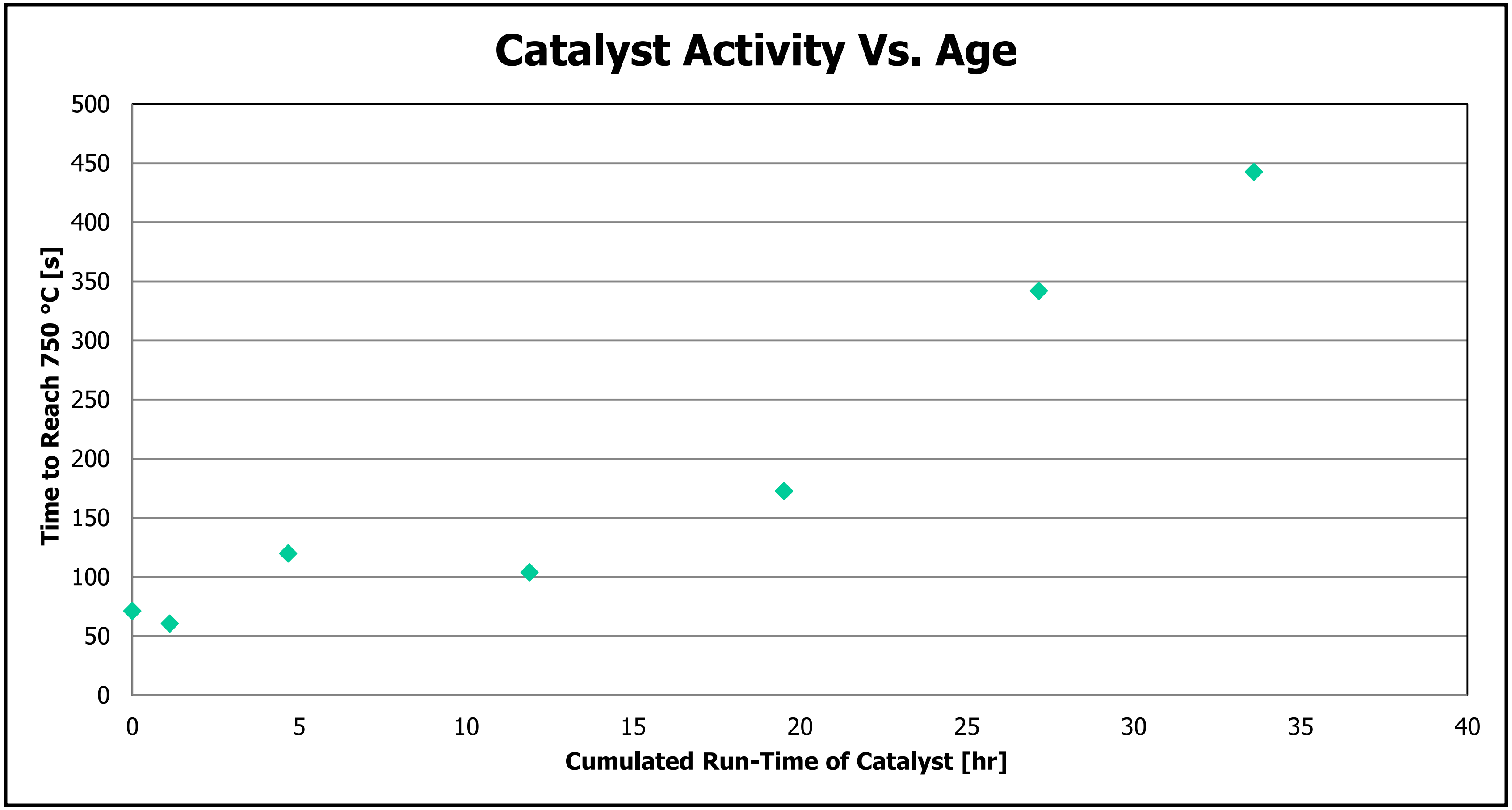
- Evidence of catalyst degradation hints at an potential upper limit on thruster lifetime.
- Research into catalyst deactivation is currently ongoing.

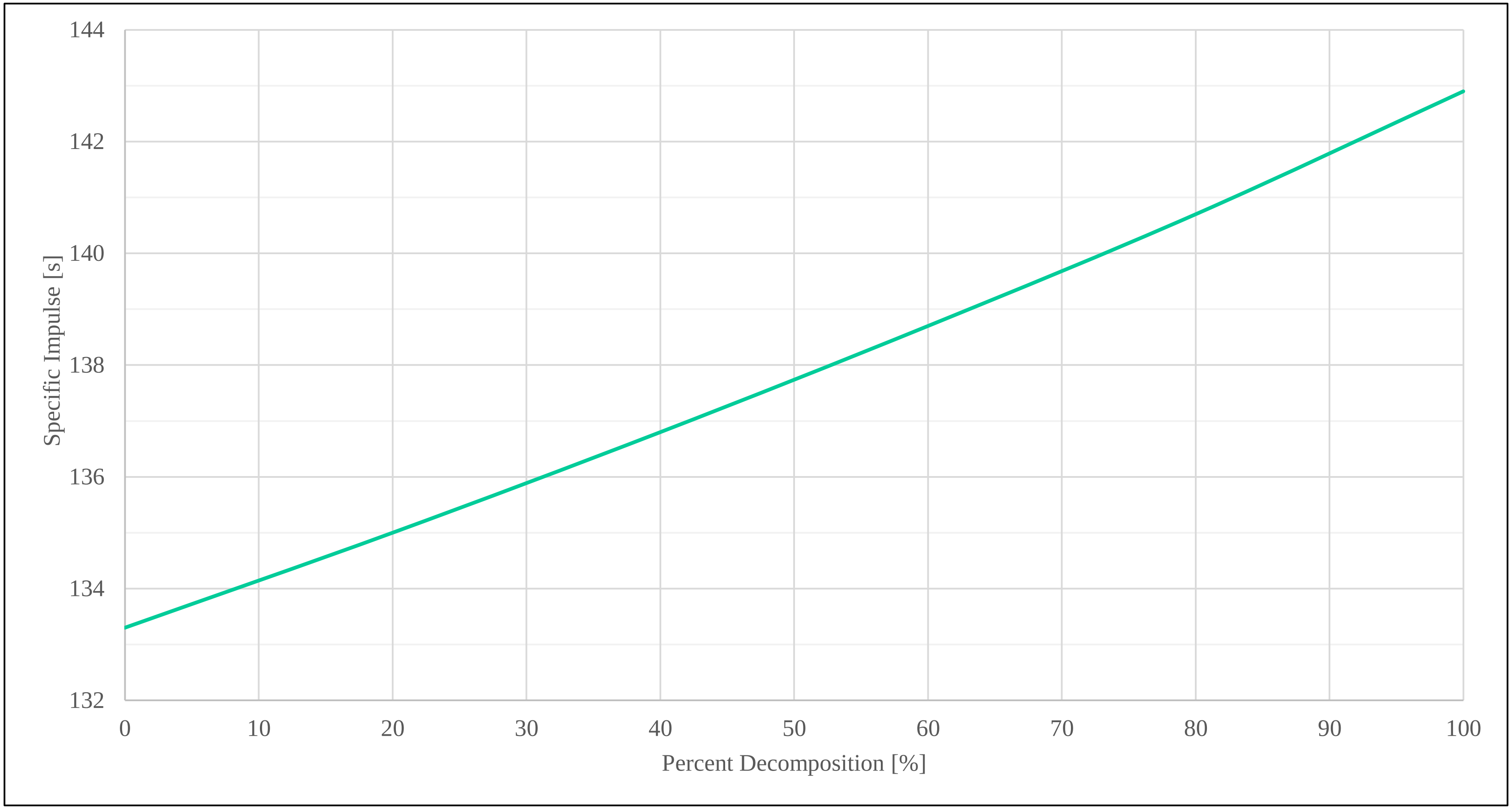
- Propellant feed system and tank are in prototype phase.
- System will be ready-to-fly by late 2016.

visit

www.utias-sfl.net

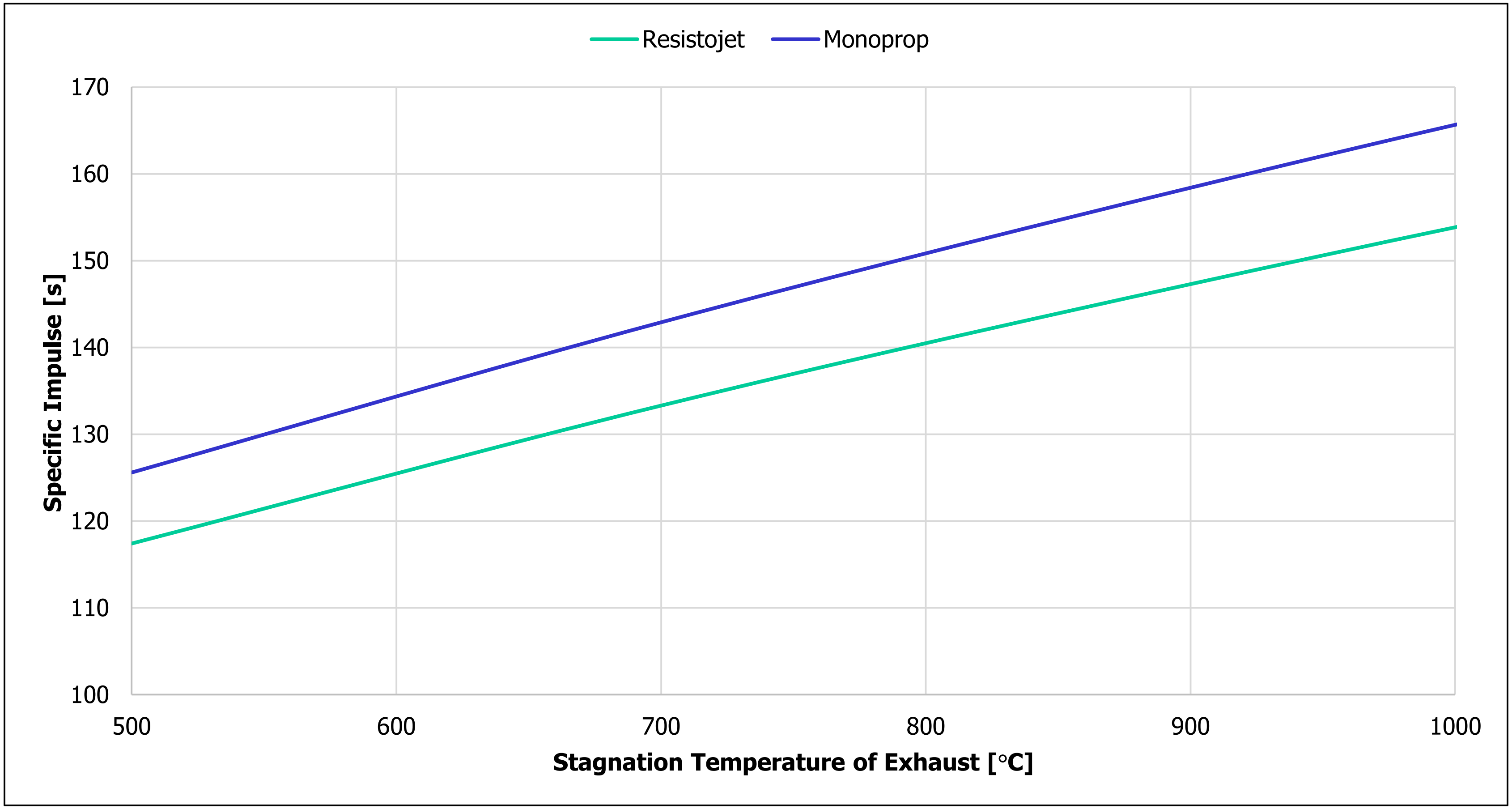
Lifetime testing



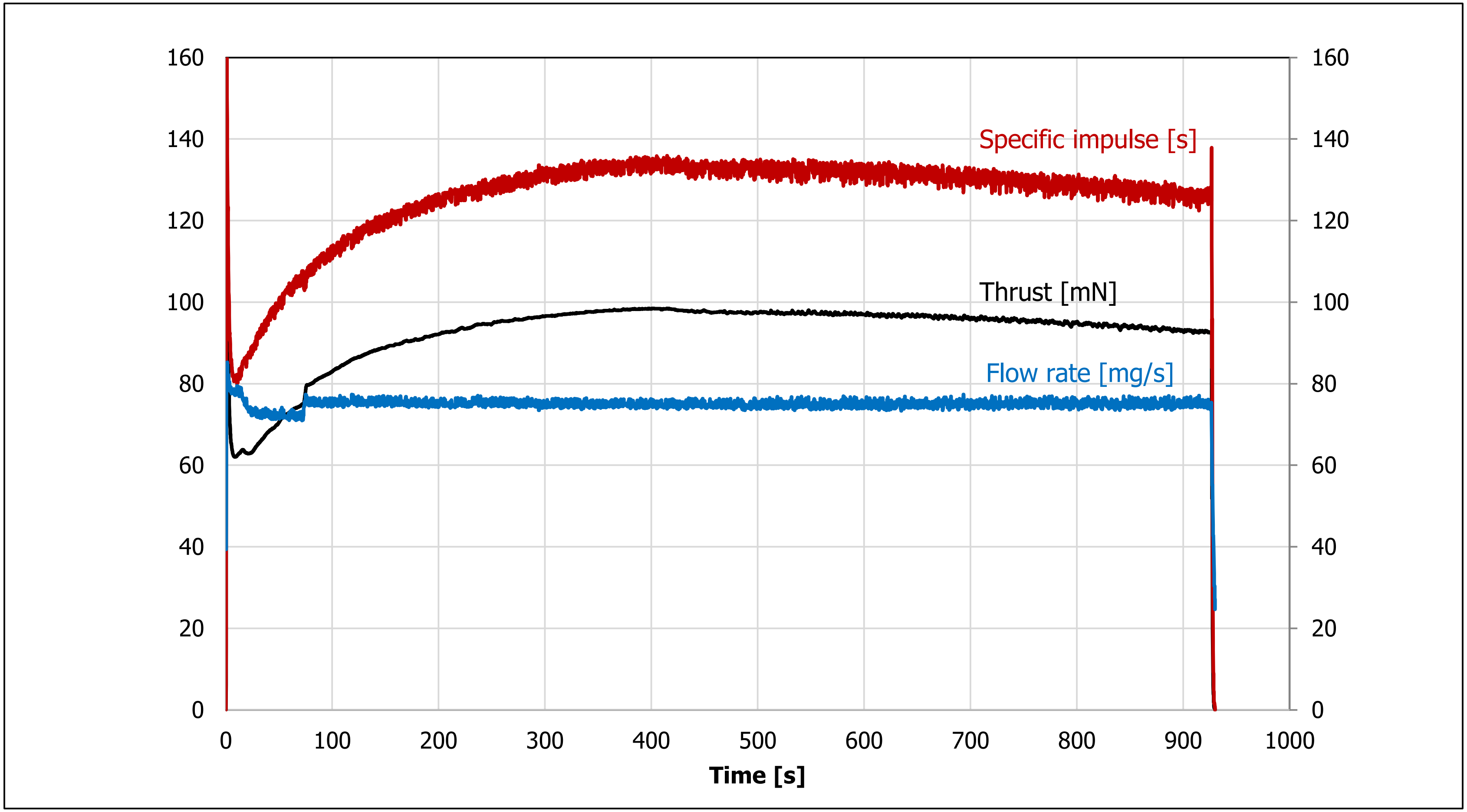


Specific Impulse [s]
144
142
140
138
136
134
132
0
10
20
30
40
50
60
70
80
90
100
Percent Decomposition [%]

Monoprop. Vs. Resisto.



Vacuum thrust test



Monopropellant

- Under the right conditions nitrous oxide will exothermically decompose according to:

$$N_2O \rightarrow N_2 + \frac{1}{2}O_2 - 82\ \frac{\text{kJ}}{\text{mol}}$$

- That's a release of 145 W per 100 mN thrust!
- This heats up the exhaust gases for free.
- There's a theoretical limit of about 1640 °C.
- There's another advantage in that the products have a lower molar mass.

Catalyst lifetime testing

- For the reference mission the system will run for a total of 40 hours.
- A dedicated lifetime test was performed to demonstrate that the system will perform as expected for the whole mission life.
- The system was run with a single catalyst pack for a total of 50.4 hours, resulting in about 25 % margin.
- Changes in catalytic activity were observed.
- Ultimately, decomposition could not be initiated after 50 hours runtime.
- System can be restarted with fresh catalyst.